

National Weather Service Local-scale Numerical Weather Prediction (L-NWP) Action Plan

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1. Introduction

Many National Weather Service (NWS) Weather Forecast Offices (WFOs) currently use experimental local applications of high-resolution (e.g., 10 km or less grid spacing) numerical weather prediction (NWP) models as an aide in their forecast operations and training programs. These applications consist of various hardware configurations and models run either at the individual WFO or in many cases, at universities or other cooperating organizations. Validation studies show that local-scale NWP (L-NWP) models capture severe hazardous storms and other small-scale phenomena not resolved by regional models such as those produced by the interaction between the synoptic flow and local terrain. There is also evidence that L-NWP information improves operational forecasts. This positive impact on NWS forecast operations along with the rapid advance of L-NWP in the 1990s, and the availability of affordable computer processing capabilities indicate that the time is right to move beyond experiment and more formally evaluate and plan for a uniform operational L-NWP capability at WFOs.

To lay the planning foundation for an operational L-NWP capability, the Office of Science and Technology (OST) hosted a series of workshops in December, 2000 and March, 2001 to develop an L-NWP action plan. The specific goal of the workshops was to develop a vision, justification, concept of operations, costs, responsibilities and a roadmap for integrating L-NWP applications into NWS operations.

From these workshops, a vision was defined:

All WFOs are provided locally-optimized operational NWP output at spatial and temporal resolutions required to meet the NWS local warning and forecast, science and technology infusion goals.

2.0 Action Plan Definition

The action plan was established to establish an operational NWS Local NWP (L-NWP) capability. The plan detailed the requirements (including costs) for two implementation scenarios defined by the Team:

- 1) Threshold Scenario - What it will take to establish a minimum capability
- 2) Optimal Scenario - What it will take to reach the vision

For each of these scenarios, the plan addressed specifically:

- Concept of Operations
- Data Assimilation
- Modeling System
- How and how often is the model run
- Forecast range and run times

- Postprocessing, products, and display
- Other
- Infrastructure Requirements and Costs
- Computational architecture
- Communications
- Data and Formats
- Other
- Training
- M&O
- Implementation Roadmap (milestones - deliverables and responsible organization)

The plan relied heavily on the December, 2000 L-NWP Workshop Report as the basis for the implementation plan. The Plan was also scalable so that implementation can be phased depending on budget. Additionally, would not require new FTE and would minimize WFO staff maintenance.

2.1 Team membership

The L-NWP Integrated Working Team (IWT) consisted of one representative from the following organizations:

Office of Science and Technology, PPD/SPB (Jeff McQueen)
 Office of Science and Technology, PPD/PMB (Mike Divecchio)
 Office of Science and Technology, MDL/MP (Dave Ruth)

National Centers for Environmental Prediction/EMC (Geoff Dimego)
 National Centers for Environmental Prediction/NCO (Bruce Webster)

Office of Climate, Weather, and Water Services, Training (Bob Rozumalski)
 Office of Climate, Weather, and Water Services, Integrated Ops. (Ashley Kells)

Office of Hydrological Development (Jay Breidenbach)

Southern Region SSD (Bernard Meisner)
 Western Region SSD (Andy Edman)

Office of Operational Systems (Fred Branski)

OAR (John McGinley, FSL)

3. Justification and Key Benefits for Operational L-NWP

The consensus of the workshop participants was that the implementation of an operational L-NWP capability at each Field Office will enable NWS to reach 2005 Strategic Plan product and service goals by:

- Providing more accurate specification (timing and location) of high impact, poorly forecast weather events such as:
 - < Precipitation and other sensible weather elements impacted by local terrain forcing caused by complex topography, land-water boundaries, etc ;
 - < Thunderstorms, precipitation bands, and precipitation type. Such improvements will improve the lead time and accuracy of flash flood warnings in the 24 hr time period;
 - < More precise predictions of TAF parameters such as clouds, cloud base and depth, and visibility thereby improving aviation forecasts accuracy and reducing false alarm rates; and
 - < Increased accuracy of marine and coastal forcing of winds and waves by resolving coastal and estuarine features not resolved by regional models.
 - < Point specific prediction for air quality or unanticipated contaminant releases.
- Supporting the seamless suite of digital weather products at higher resolution and accuracy by extending centrally-produced NWP to locally-produced NWP at Field Offices.
- Utilizing local data sets more advantageously by ingest and assimilation into the model forecast.
- Increasing the understanding of the meso/micro-scale aspects of the local atmosphere by:
 - < Visualizing the local atmosphere in 4-D
 - < Developing and confirming conceptual models
 - < Compiling model outputs for real-time operational case study analogs
- Broadening the conduit for Science and Technology infusion by:
 - < Increasing opportunities for collaboration with the research community
 - < Leveraging NWP systems expertise and knowledge across NWS
 - < Training and education on NWP and local-scale phenomena
 - < Injecting NWS experience with the community model back into research
 - < Providing a broad testing environment for community model upgrades

Lessons learned from local model runs as well as changes recommended by WRF community would go through the NCEP testbed

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4. Vision and Proposed system

On the basis of the discussions detailed in the L-NWP workshop report, the participants formed the following vision statement for NWS operational L-NWP:

All WFOs will be provided locally-optimized operational NWP output at spatial and temporal resolutions required to meet NWS local warning and forecast, and science and technology infusion goals.

Through a consensus-building process, the workshop participants discussed the pros and cons of each proposal and then developed a consensus hybrid proposal. The optimum “Workshop Proposal” stated that every WFO have two L-NWP capabilities: One operating in Standard “black box” configurations for daily operations and one for Research/ Training applications. In subsequent meetings, only one standard black box could be afforded with the option of the WFO to use some processors for research if desired. For this single workstation capability, two configurations are proposed in Table 1 below: A “Desired” configuration and a “Threshold” configuration. The latter would be the minimum configuration required to begin supporting operational L-NWP. Operations and Maintenance (O & M) support was included for both configurations. The costs are divided for initial and recurring costs for each element (e.g.: initial/recurring in \$1000's). O & M staff would be responsible for upgrades and new installations of the assimilation, model and post-processing software as well as ensuring that the NCEP initialization and boundary conditions grids are tiled for real-time transmission to the RFCs and WFOs.

The modeling system proposed would be Weather Research and Forecasting model (WRF) being co-developed by NWS/NCEP, NCAR, OAR/FSL, the Air Force Weather Agency (AFWA) and other modeling institutions. The WRF is ideal for L-NWP as it is being developed specifically for non-hydrostatic scale processes ($\Delta x = 1-10$ km). The system would be run on a multi-processor Linux PC. The system would include an assimilation capability, model, verification and post-processing for ingest into AWIPS. Resolution would be 2-5 times the NCEP model resolution depending on the local WFO configuration. An additional dedicated WAN T1 line could be installed to improve transfer of NCEP first guess fields from the RFCs to the WFOs, but is not required as current capabilities are adequate ($\frac{1}{2}$ hr per 33MB file transfers). The model would be run at least 4x/day and out to 24 hours. Outputs at a minimum of 30 minutes time intervals would be stored on the PC system, thereby requiring at least 1 additional gb of storage. Configuration management would be performed at OS and NCEP as the national and local WRF codes would be similar. Support would be provided by OS on an 8-5 M-F basis. Additional details are shown in Table 1 and a proposed cost-effective solution for each L-NWP item is shaded in the table.

L-NWP Action Plan Table

FEATURE	OPTIMUM	THRESHOLD	RESPONS. ORG	COST per site (initial/recurring)
Location	All WFOs, RFCs & CWSUs		Regions determine	
		All WFOs/RFCs have run capability, All have access to outputs (135)		
Computer Architecture	8 cpus /fast ethernet/switch 2gb memory(or SOA)		OST	15 k/ 5k per yr
		2 cpus/512mb Linux PC		4k / 1.3k per yr
Software	Linux, compilers, support software (MPI, etc)		OST	0.1k/0.033 k per yr
		Linux		
Resolution	5x NCEP resolution (4 km)		Field offices	
		2x NCEP resolution (10 km)		
Domain	1600 km ² outer grid 400 km ² inner grid		Field offices	
		1000 km ² single nest		
Run time	36 hr forecast, 4x/day & on demand (run outside AWIPS LAN)		Field offices	
		24 hr forecast,4x/day or on demand (run outside AWIPS LAN)		

FEATURE	OPTIMUM	THRESHOLD	RESPONS. ORG	COST per site (initial/recurring)
Model	WRF		NCEP	included in O&M
		“”		
Standard init/FDDA	WRF state-of-art assimilation at all sites. Pre-forecast assimilation (not cycled)		NCEP	included in O & M. development of model and FDDA leveraged from NCEP & WRF “”
		WRF standard initialization (static analysis, background only, 3DVAR if available)		
Additional assimilation capability	LAPS/ADAS cloud, hydrometeor analysis & complex terrain into state of art WRF		FSL/WR/ NCEP	1.5 person yrs
		none		none
Display	Ingest gridded fields into AWIPS		OST	2 person mo.
		same as optimum	OST	“”
Post- processing	Interface with IFP software at WFOs & RFCs		OST	coordination/testing (2 person mo.)
		“”		
Storage/ exchange data formats	GRIB/NetCDF/BUFR at sub-15 minute output		OST	additional AWIPS storage for all fields for 2 runs (1gb additional)
		GRIB/NetCDF at 30 minute output	OST	0.5 gb additional for current runs

FEATURE	OPTIMUM	THRESHOLD	RESPONS. ORG	COST per site (initial/recurring)
Verification	national std mesoscale metrics including sensible wx fields Improved mesoscale verification MDL/NCEP/FSL		OST/NCEP/ FSL	2 person yrs/ 8 person mo.
		Incorporate existing metrics extended to TAFS element	NCEP/FSL/ OST	1 person yr/4 person mo. Eventually leverage off WRF
Archive	Archive full local gridded output of all fields for every operational run		Field offices	DVD burner (3 k/ 2 k)
		Archive initialization & model version archive for every operational run	Field offices	CD ROM burner (0.5k/0.1k)
Support/ O&M	24x7, new installations, upgrades, create B.C files		OS/NCEP/ FSL	5 person yrs recurring
		8x5 support, 24x7 on-call, new installations, upgrades, create BC files	OS/COMET	1 person yr recurring
Training	residence courses on local-scale models		OS/COMET	1.0 k per participant
		on-line documentation	OS/COMET	1 person mo.
Comms	Tiled full resolution fields for initial & boundary conditions ½ hr download of 100mb/run		OST/OPS/ NCEP	\$1956/yr for additional 256k line.

FEATURE	OPTIMUM	THRESHOLD	RESPONS. ORG	COST per site (initial/recurring)
		Ftp tiled grids and paired-down BC Files(½ hr of 33mb/run)	OST/OPS/ NCEP/Region	<i>see O&M</i>
Reliability/ Backup strategy	2 nd hot-swappable machine for backup and research, 95% reliability goal			15k/ 5k per yr
		Use remaining processors		
configuration management	local model code is NCEP code (NCEP manages configuration).		NCEP	included with O&M
		“”	“”	

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5. Responsibilities

NWS/NCEP

NWS/NCEP would be responsible for customizing the localized Work-station Eta and eventually the WRF model for configuration at the local field office. NCEP would also be responsible for development of the local model verification system. Model change management would be supported by NCEP and OS since the model would be the same as the one run nationally.

NWS/WFO

NWS/WFOs would be responsible for evaluating the utility of the model performance for their localized areas. The WFOs would be responsible for identifying problems with the hardware or software and reporting these problems to the NWS/OS & OST for solutions.

NWS/OS

NWS/OS would work with NCEP on customizing and testing the WRF model for configuration at the local field offices. OS would also provide support and develop training materials on software issues related to model performance.

NWS/OST

NWS/OST/PMB would develop a more detailed implementation plan once this action plan was accepted. OST/MDL would be responsible for ensuring compatibility of model outputs with AWIPS platform for visualization at the local WFOs. OST/MDL would also lead the development of a customized verification system.

NWS/OOS

NWS/OOS would be responsible for purchasing and deploying the Linux workstations for running the localized models.

OAR/FSL

OAR/FSL would work with NCEP on customizing and implementing the standard initialization system for the localized Eta and WRF models. FSL would also support NCEP and OST/MDL on development of an model verification system run at the local WFOs.

6. Performance Measures

It is expected that the availability of localized weather prediction products to the WFO's would improve accuracy, specificity and timeliness of weather products substantially. The following performance measures were obtained from recent results in the literature when comparing L-NWP predictions to coarser model forecasts:

- Improve wind forecasts by 15%.
- Decrease temperature forecasts errors by 1-2° F.
- Improve QPF 0-12 hr forecasts by a factor of 2.
- Improve flash flood warning lead time to 47 minutes thru improved QPF.
- Improve visibility forecasts by 27%.
- Improved warnings and forecasts will mitigate loss of life and property in coastal zones through better storm avoidance and preparedness.
- Creation of new nowcast/forecast products for various constituents (e.g: marine community, energy sector, fire weather, air quality).

7. Risks

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Problem: Current communications may not support transfer of high resolution NCEP fields for optimal L-NWP system.

Requirement: The capability to download 100mb/run within 1 hr (0.22 mb/sec) is needed at all operational sites.

Recommendation: Ensure WAN has this capacity

Action: Communications were found to be adequate for threshold scenario as the WANs are currently at 0.256 to 0.512 mb/sec rates. Therefore, no additional communications improvements are required for the threshold scenario.

8. Roadmap

FY01

Begin <u>Planning:</u>	12/01/00		
L-NWP IWT finalize costs	4/01/01		OST/SPB&PMB
Action plan delivered	5/31/01		OST/SPB
Corporate board presentation	6/15/01		OST/SPB
Begin implementation plan	7/01/01		OST/PMB
Complete implementation plan	9/01/01		OST/PMB

FY02

Begin <u>Development:</u>	10/1/01		OS, OST, NCEP & OAR
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WRF assimilation development			
to ingest local data	3/1/02	12 Staff mo	OAR & NCEP
WRF development for L-NWP	6/1/02	12 Staff mo	NCEP&OAR
Customize verification system	10/1/02	12 Staff mo	OST/MDL, NCEP & OAR
Test IFPS & AWIPS connections	10/1/02	4 Staff mo	OST/MDL
Develop training materials	10/1/02	1 Staff mo	OS
Configuration management docs	12/1/02	2 staff mo	OS

FY03

Create paired-downed LBC files	12/1/02	4 Staff mo	NCEP
WRF Testing/Evaluation	1/1/03	6 Staff mo	OS, OAR & NCEP

Deployment:

Purchase JAX workstation	12/1/02	N/A	OOS
Deploy system at JAX, FL	12/15/02	1 Staff week	OOS & WFO/IT
Install WRF software	1/1/03	1 Staff mo	OAR & OS
JAX Evaluation	6/1/03	1 Staff mo	WFO/SOO

Purchase additional workstations	2/1/03		OOS
Install WRF software	3/1/03		OAR & OS
Deploy system at 5 CSI sites			
Melbourne, FL	3/15/03		OS & OAR
Portland, OR	4/01/03		OS & OAR
Medford, OR	4/15/03		OS & OAR
Los Angeles, CA	5/1/03		OS & OAR
San Diego, CA	5/15/03		OS & OAR

Begin 12 Fire Weather/Energy sites Deployment			
Fort Worth, TX	6/01/03		OS & OAR

San Antonio, TX	6/15/03	OS & OAR
San Angelo, TX	7/01/03	OS & OAR
Lubbock, TX	7/15/03	OS & OAR
Sacramento, CA	8/01/03	OS & OAR
San Francisco, CA	8/15/03	OS & OAR
Pendleton, OR	9/01/03	OS & OAR
Spokane, WA	9/15/03	OS & OAR
Boise, ID	9/30/03	OS & OAR

FY04

Continue deployment at CSI, Fire Weather & Energy sites.

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9. Budget (Rough order of magnitude in \$1000)

	Responsible	Staff mo.	2003	2004	2005	2006	2007	2008	Complete
One Time Investments									
Assimilation development & incorp local data	OAR& NCEP	12	120.0	40.0	40.0	40.0	40.0	40.0	320.0
WRF development & assimilation coupling	NCEP,OAR	12	120.0	40.0	40.0	40.0	40.0	40.0	320.0
WRF testing	NCEP,OAR,OS	6	60.0	20.0	20.0	20.0	20.0	20.0	160.0
Create NCEP paired-down boundary files	NCEP	4	40.0	40.0	40.0	40.0	40.0	40.0	240.0
AWIPS/IFPS integration	OST/MDL	4	40.0	15.0	15.0	15.0	15.0	15.0	115.0
Model verification system development	OST, NCEP	12	120.0	40.0	40.0	40.0	40.0	40.0	320.0
Online training documentation	OS	1	10.0	10.0	10.0	10.0	10.0	10.0	60.0
Configuration management documentation	OS	2	20.0	20.0	20.0	20.0	20.0	20.0	120.0
Subtotal			530.0	225.0	225.0	225.0	225.0	225.0	1655.0
Per-Site costs									
Workstation	OOS		25.0						
Install assimilation & model software	OS, OAR	1	10.0						
Install hardware	WFO	0.25	2.5						
Subtotal			37.5	975.0	975.0	975.0	975.0	975.0	4980.0
Recurring O&M/support									
Trouble shooting support	OS, NCEP	3	30.0	30.0	30.0	30.0	30.0	30.0	180.0
Upgrades & Installation	OS, NCEP,OAR	18	180.0	180.0	180.0	180.0	180.0	180.0	3080.0
Hardware maintenance	OOS	1	10.0	10.0	10.0	10.0	10.0	10.0	60.0
Subtotal			220.0	220.0	220.0	220.0	220.0	220.0	1320.0
Total			887.5	1420.0	1420.0	1420.0	1420.0	1420.0	8025.0
Number sites per year			2	26	26	26	26	26	132

10. Alternatives

Several alternatives were considered regarding where the high-resolution model should be run. The group decided that capability should exist to run the fine-scale models locally at the WFO for the following reasons:

- The capability to run models on demand for rapidly evolving weather systems and unanticipated contaminant releases
- Timely, high resolution outputs would be available at the WFOs at a lower cost than can be done at NCEP or the RFCs. Significant communications upgrades would be required to transfer the fine-scale model output from NCEP or the RFCs to the WFOs. See Appendix A for more details.
- More effective S&T partnering would be possible with the WFOs and local universities.
- The WFOs could customize the model for specific local weather and to run various scenarios.

Appendix A

Costs for running a 2 km L-NWP at NCEP:

Communications upgrades would be required to transfer a typical RFC sub-grid high-resolution file. Assuming an RFC sub-grid domain encompasses about 1200x1800 km, the file size for a 2 km resolution file would equal:

$$600 \times 900 \times 45 \text{ levels} \times 8 \text{ fields} \times 4 \text{ bytes/field} \times 8 \text{ bits/byte} = 6216 \text{ mb/time period} \\ * 24 \text{ hrs} * 4 \text{ time periods/hr} \sim 597 \text{ gb file}$$

To transfer this file from NCEP to each RFC would require about 4 T3 lines (45 mb/sec) per RFC to transfer the data in 1 hr. Assuming \$100k/yr to rent 1 T3 line, the cost would be about \$5.2 M/yr. In addition, NWS Gateway and RFC telecommunications would have to be upgraded to T3 capabilities. This latter cost would easily dwarf the T3 line costs

In addition, sub-gridded files covering each WFO (~ 400x400 km or around 504 mb/time period 4.8 gb file transferred in 1 hr=1.33 mb/sec) would then be sent from each RFC to WFO in its region. Around 1 T1 lines would be required per WFO or around \$1.22 M/yr total. Additionally WAN routers at each RFC and WFO would be upgraded to support the dedicated T1 connections.

Therefore, the cost for running the model centrally far exceeds the cost for running locally while also eliminating the potential benefits gained when running the model locally (e.g.: run the model on demand, customized configuration, etc).